STATE OF CALIFORNIA
HIGHWAY TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

THE USE OF SUB-AUDIBLE ROCK NOISE (SARN) RECORDINGS TO MONITOR SLOPE STABILITY

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ABSTRACT

The Materials and Research Department of the California Division of Highways, using equipment developed by the University of California, is evaluating the practicality of using SARN rates to monitor slopes. Highway construction around the San Luis Reservoir, located in the Central Coast Ranges of California, was chosen for the test area. Several slides had already occurred in cuts under construction. Three locations proposed for future cuts were chosen as monitoring sites. SARN records were taken at various times during construction and through the following winter rainy season.

Results of the study are encouraging. The SARN rates were high during construction and decreased following construction. The rates then increased during the rainy season and decreased during the dry season. No major slides occurred at any of the monitoring locations, but small local failures appear to be reflected in the SARN records.

The signal-to-noise ratio can be improved by modification of the equipment. Simultaneous recordings from two adjacent probes will be used for future work. These improvements should provide greater ease in interpreting the SARN records.

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INTRODUCTION

In 1962, the Materials and Research Department of the California Division of Highways and the University of California began a cooperative research project. In the first phase of the study, accomplished by the University of California, instrumentation capable of recording sub-audible rock noise was fabricated. It was also demonstrated in this phase that rock under stress emitted sub-audible noise. The SARN rates in active landslides were higher than those in stable areas.

The second phase, done by the California Division of Highways, evaluated the practicality of using SARN recordings to monitor slope stability. This paper presents the results of the second phase.

The first studies of rock noise were conducted by the U.S. Bureau of Mines. In some deep mines, audible noises preceded a rock burst. Leonard Obert (1941) found that rock under stress also emitted sub-audible noises and that the number of noises increased prior to a rock burst. Obert and Duvall (1942) reported further results of rock noise studies in relation to rock bursts. In 1961, F. D. Beard wrote a short article on predicting slides in cut slopes wherein he used sub-audible rock noise. R. E. Goodman reported the first phase of this

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study at the Highway Research Board meeting in January, 1965.

ACKNOWLEDGEMENTS

I would like to acknowledge the work of Dr. R. E. Goodman and Mr. Wilson Blake, of the University of California, in completing the first phase of the study. This project was begun as a result of a suggestion from Dr. Goodman. Several people at the Materials and Research Laboratory have been most helpful. In particular, I would like to mention the work of Mr. Colin Love in helping to obtain field records and the work of Mr. Dave Coombs in making visual records and counting the noises. The funds for this study were provided by the U.S. Bureau of Public Roads.

EQUIPMENT

The equipment used in this study was that developed by the University of California. It consists of a geophone, an amplifier, a power supply, and a portable tape recorder. The geophone is a barium titanate ceramic disc mounted on a cantilever and enclosed in a protective lucite case. The noises picked up by the geophone are amplified and recorded on tape. In the laboratory, these tapes are played into a visicorder. The SARN rates are then determined from these visual records.

TEST SITE

The highway relocation around the San Luis Dam project was chosen as the site for testing the application of SARN rates to highway problems. The SARN records were to be examined to see if they reflected changes in the stability of the rock. The ease of using the equipment was also to be evaluated.

Construction had begun on this highway relocation which is located in the Central Coast Ranges of California about 160 miles southwest of Sacramento. The western six miles of the project would be constructed in the Franciscan Formation of Upper Jurassic-Cretaceous age. Most of the material was sandstone and shale that had been slightly metamorphosed. Considerable faulting and shearing had taken place and the rock was quite fractured.

Construction was progressing from east to west and several slides had occurred in cuts constructed in the Franciscan Rocks. The type of sliding that occurred deserves special note. Within the cut faces, fractures parallel to centerline and dipping steeply into the cut face had a thin layer of clay on their surface. Blocks of rock began tilting into the roadway and the failure worked progressively up the cut slope. The overall effect was of a stack of dominoes that had been pushed over.

Although some of the westernmost cut slopes were redesigned, the possibility of further sliding existed and two of the larger cuts still to be constructed were chosen for monitoring sites.

RECORDING PROCEDURE

Monitoring was done at grade and on the bench 60 feet above grade at Sta. 44 and Station 46. At Station 95 monitoring was done at grade, on the lower bench 60 feet above grade and on the upper bench 140 feet above grade.

Recordings were made at these sites on nine separate occasions. Three of the dates were during construction, three were during the winter rains, and three were following the rains.

For each recording, the probe was placed next to a hard rock face and covered with soil. A ten minute recording was made. The recordings, thus made, were taken to the laboratory and played through a visicorder.

Counting of the visual record proved to be a very difficult problem. Noise from construction equipment, traffic noise, wind noise, and noise generated by the apparatus itself all were recorded on the tape. Much of the noise from construction equipment and from traffic could be identified and eliminated. Wind noise could be heard on the tape but did not seem to appear on the visual record. Small amplitude peaks generated by the SARN equipment were impossible to distinguish from rock noise. In order to use the tapes, an arbitrary counting method was chosen. All amplitudes greater than five times the background were counted. With this counting method, absolute SARN rates are not obtained, but the rates are relative.

DISCUSSION OF RESULTS

The count rates that were determined for the various recording dates at Station 44 at grade are shown in Figure 1. The count rates for the dates November 8, 1964, December 28, 1964, and January 7, 1965, taken during the rainy season, show a steady increase over the rate for October 25, 1964. The count rates for the dates April 12, 1965, June 24, 1965, and September 15, 1965, show a decrease from the high recorded in

January. Traffic noise on June 24, 1965, and September 15, 1965, made counting difficult and the results are less reliable than other counts.

The count rates that were determined at Station 44 on the bench, shown in Figure 2, also show an increase in rate during the winter rains. The high count again drops off following the rainy season. Again traffic noise affected the recordings on June 24, 1965, and September 15, 1965.

At Station 46 at grade (Figure 3) the counts increase during the rains. However, the highest count at this location, recorded on April 12, 1965, was obtained a few days after a local slide had occurred at this station. Recordings for June 24, 1965, and September 15, 1965, show a decreased rate although the reliability of the counts is affected by traffic noise.

The pattern of counts determined for Station 46 on the bench (Figure 4) is very similar to the pattern obtained at Station 44 at grade.

The count rates that were determined for the recording dates at Station 95 at grade (Figure 5) show a very slight increase during the rains. The highest count was recorded on April 12, 1965, and coincides with the occurrence of a local slide about 250 feet away near Station 98. However, information obtained by the University of California during the first phase of this study indicates that rock noise originating more than 100 feet from the geophone would not be picked up. Traffic noise could not be separated and eliminated from the June 24, 1965, recording. The September 15, 1965, recording is somewhat questionable for the same reason.

At Station 95 on the lower bench, the counts steadily increase (Figure 6) from a low on October 25, 1964, to a high on September 15, 1965. The recording for June 24, 1965, was not usable because of traffic noise.

The pattern of counts for Station 95 on the upper bench (Figure 7) is very similar to that of Station 95 on the lower bench (Figure 6).

The steady increase in counts obtained on the benches at Station 95 suggests a decrease in stability within this area. However, there is no visual evidence of instability at the present time.

CONCLUSIONS

The data from this study has been used to reach the following conclusions:

The SARN rate reflects the stability of the immediate area. The number of counts increases as stability decreases. With the equipment used in this study, the counts are relative rather than absolute. Therefore, patterns or trends are more significant than actual values, excluding extremes of no noise and excessive noise.

The equipment used in this study was simple to operate and could be handled by one man in the field. However, the recordings obtained with the equipment and by the field method used for the study, are very difficult to interpret. We believe that interpretation of records could be greatly simplified by making improvements in the equipment to obtain a better signal to noise ratio, and by changing field techniques. These changes would include the making of simultaneous recordings at each site and drilling holes for the placement of the probe. These changes are in agreement with techniques suggested by the University of California in their report on Phase I. We feel that the greater ease of interpretation of records would more than offset the increase in gear required for the field recordings.

In summary, the results to date are encouraging enough to warrant further work on developing the SARN method for monitoring cut slopes.

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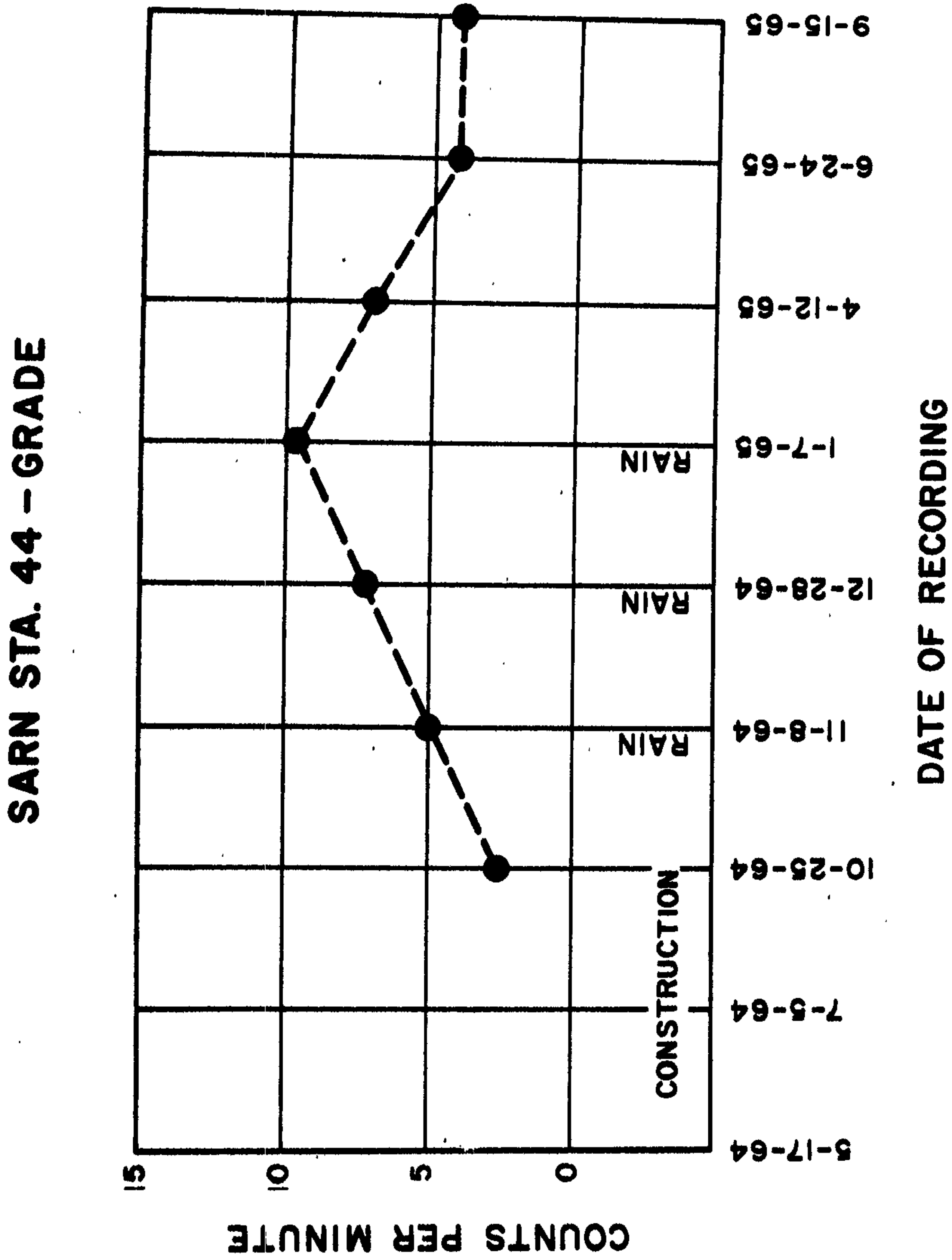
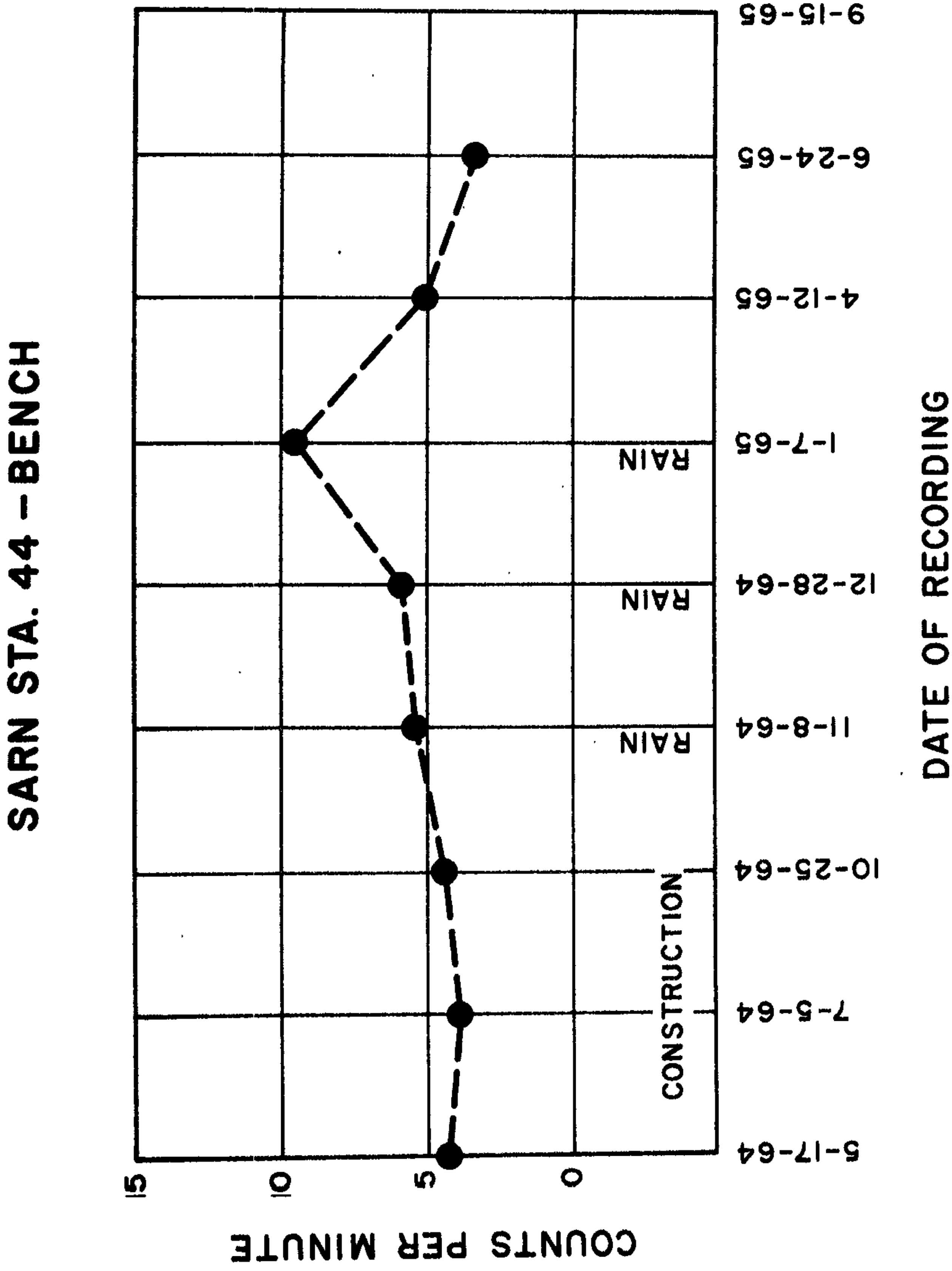
FIGURE 1



SARN STA. 44 – GRADE
COUNTS PER MINUTE
15
10
5
0
DATE OF RECORDING
5-17-64
7-5-64
10-25-64
11-8-64
12-28-64
1-7-65
4-12-65
6-24-65
9-15-65
CONSTRUCTION
RAIN
RAIN
RAIN

FIGURE 2



SARN STA. 44 – BENCH
COUNTS PER MINUTE
15
10
5
0
DATE OF RECORDING
5-17-64
7-5-64
10-25-64
11-8-64
12-28-64
1-7-65
4-12-65
6-24-65
9-15-65
CONSTRUCTION
RAIN
RAIN
RAIN

FIGURE 3

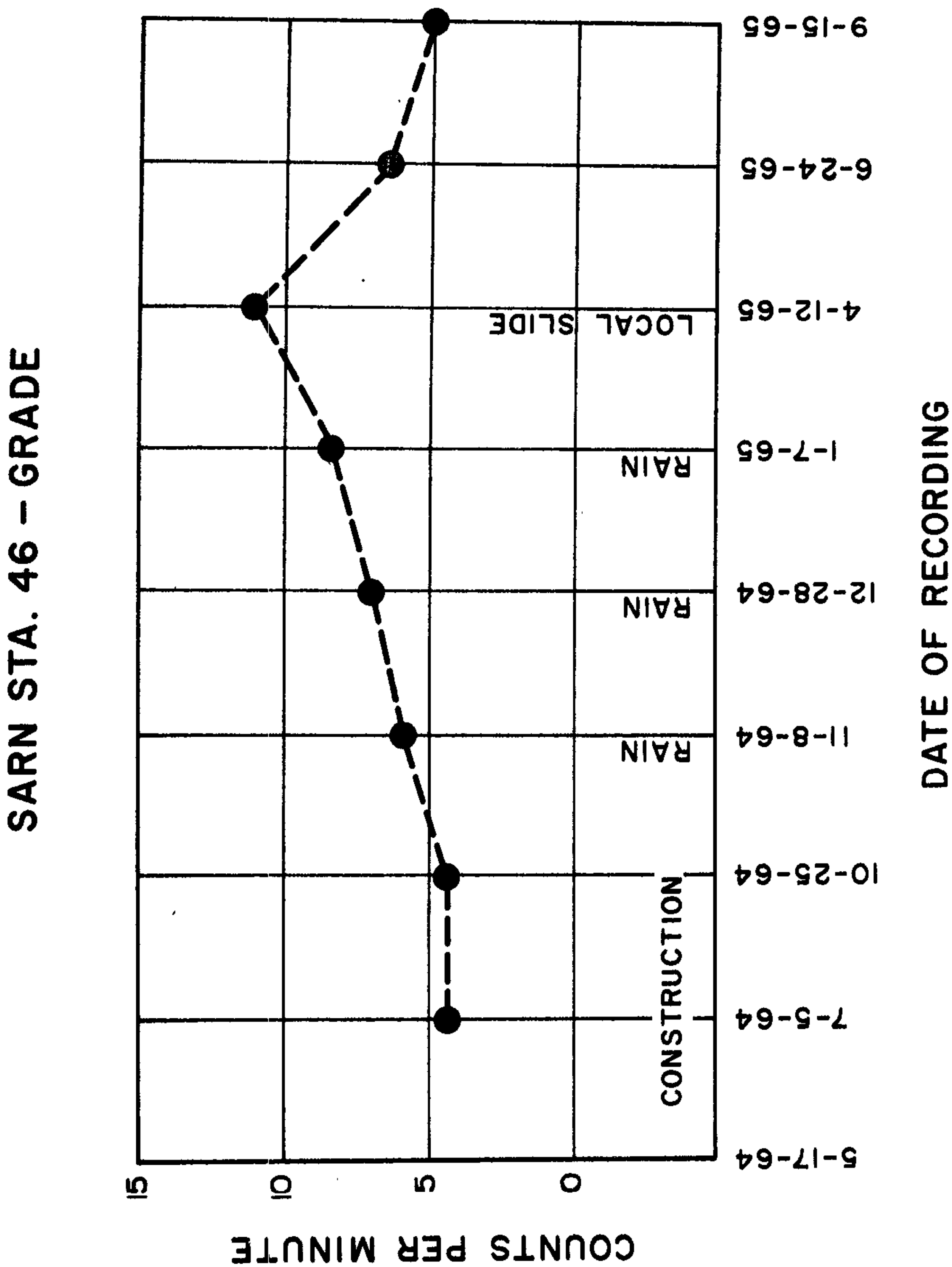
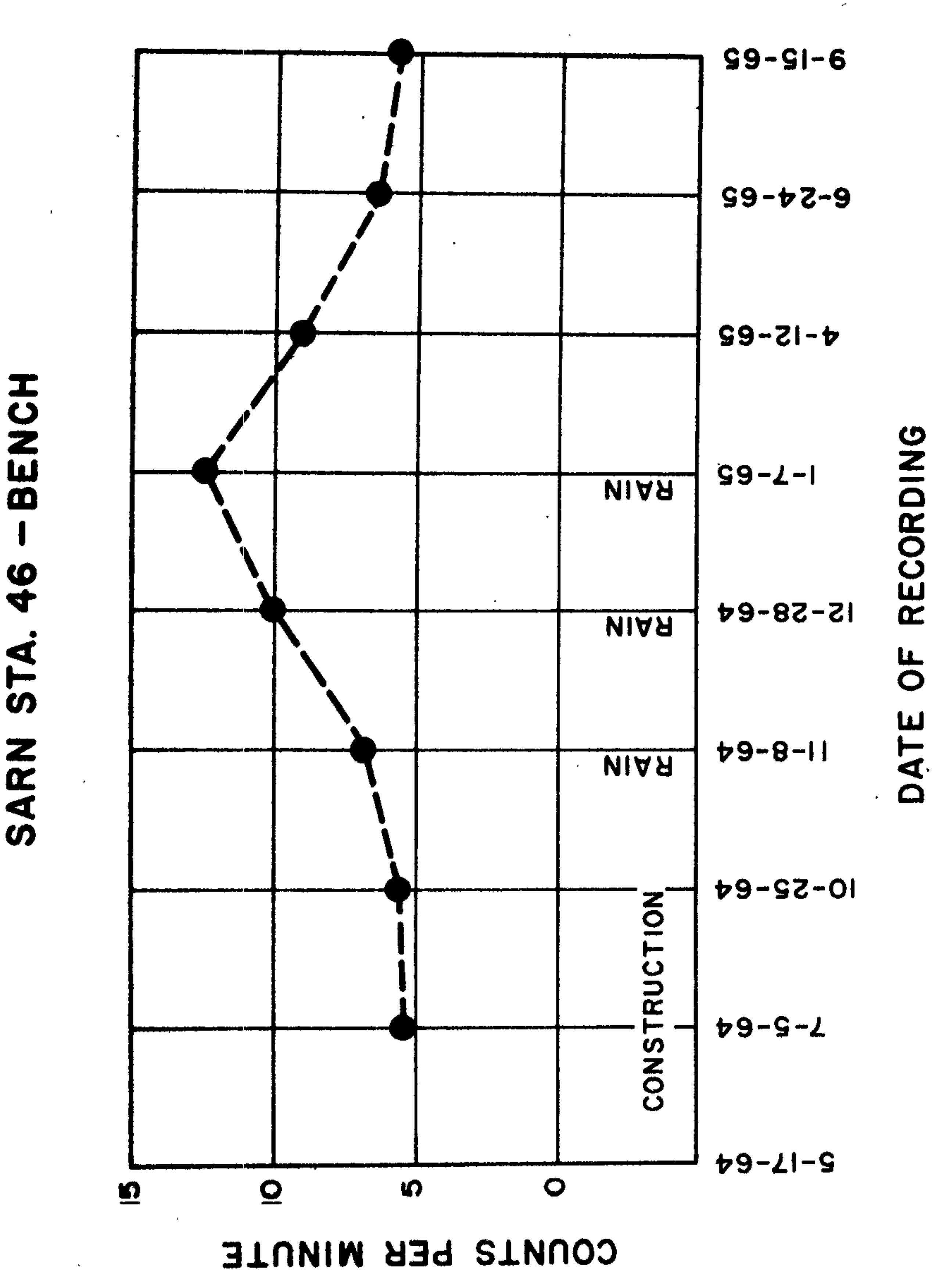

SARN STA. 46 – GRADE
DATE OF RECORDING
COUNTS PER MINUTE
15
10
5
0
5-17-64
7-5-64
10-25-64
11-8-64
12-28-64
1-7-65
4-12-65
6-24-65
9-15-65
CONSTRUCTION
RAIN
RAIN
RAIN
LOCAL SLIDE

FIGURE 4



SARN STA. 46 — BENCH
COUNTS PER MINUTE
15
10
5
0
DATE OF RECORDING
5-17-64
7-5-64
10-25-64
11-8-64
12-28-64
1-7-65
4-12-65
6-24-65
9-15-65
CONSTRUCTION
RAIN
RAIN
RAIN

FIGURE 5

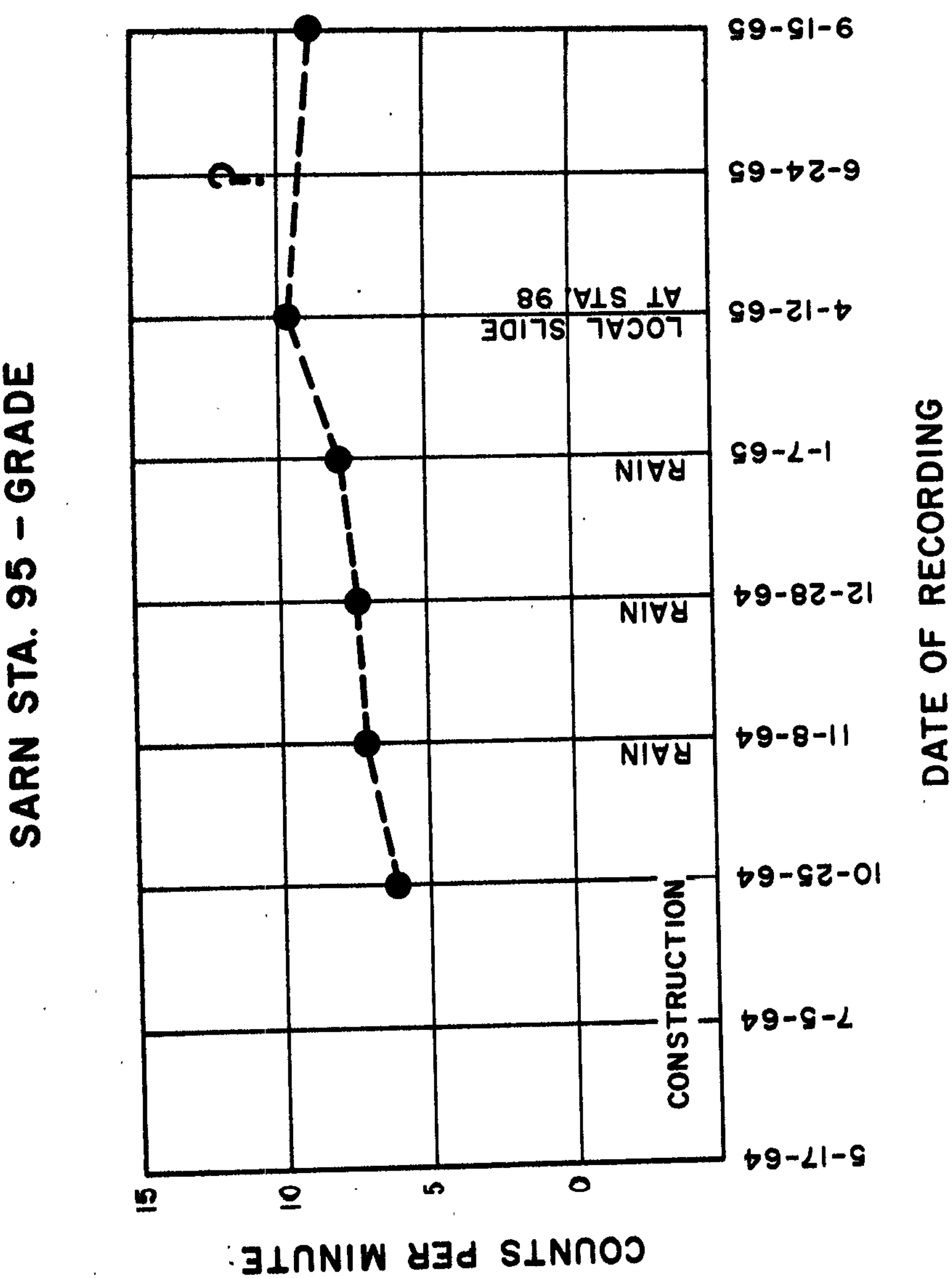

SARN STA. 95 - GRADE
DATE OF RECORDING
COUNTS PER MINUTE
15
10
5
0
5-17-64
7-5-64
10-25-64
11-8-64
12-28-64
1-7-65
4-12-65
6-24-65
9-15-65
CONSTRUCTION
RAIN
RAIN
RAIN
LOCAL SLIDE
AT STA. 98
?

FIGURE 6

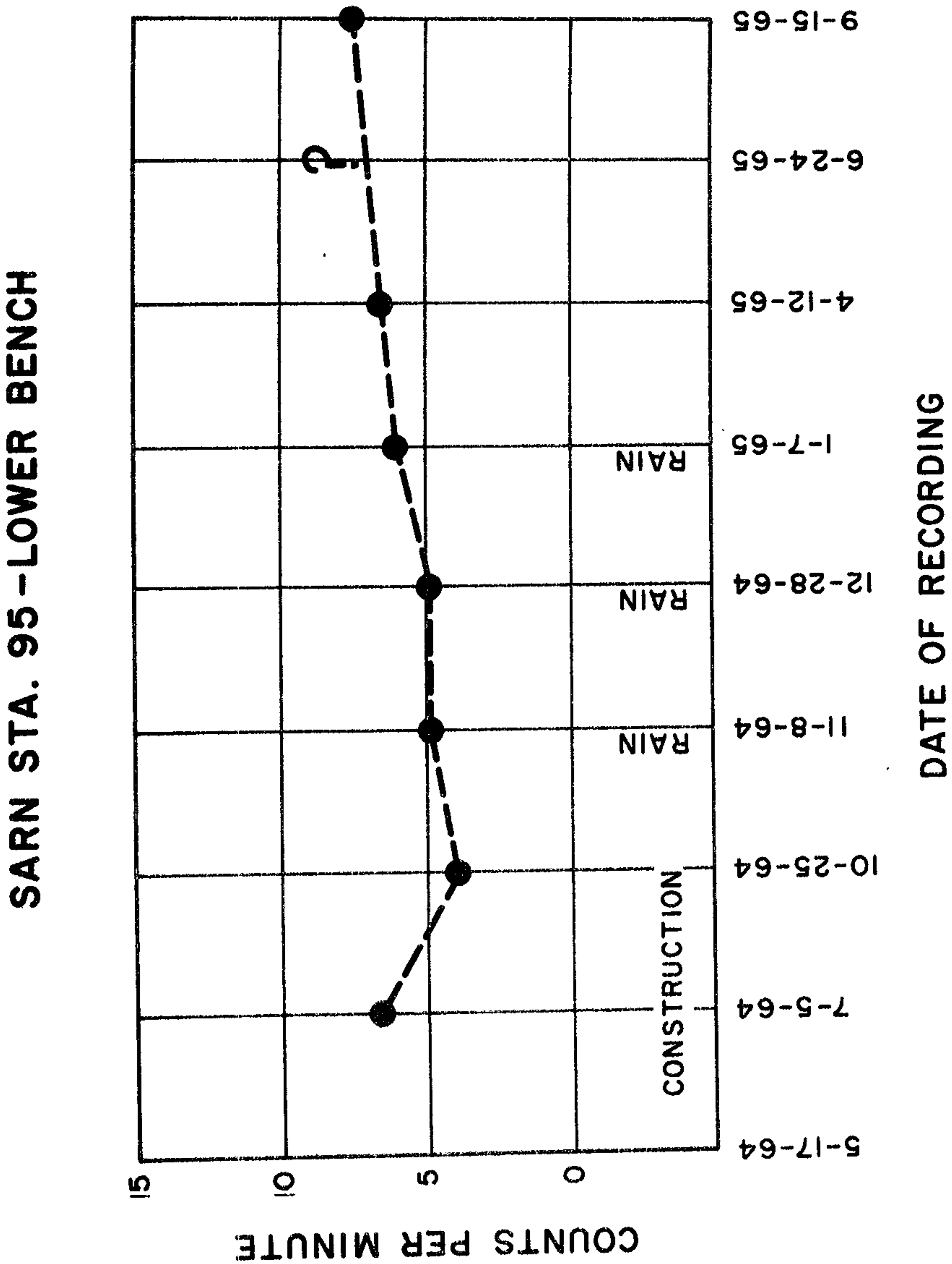

SARN STA. 95 - LOWER BENCH
DATE OF RECORDING
COUNTS PER MINUTE
15
10
5
0
5-17-64
7-5-64
10-25-64
11-8-64
12-28-64
1-7-65
4-12-65
6-24-65
9-15-65
CONSTRUCTION
RAIN
RAIN
RAIN
?

FIGURE 7

SARN STA. 95 – UPPER BENCH